

On-site underground background measurements for the KASKA reactor-neutrino experiment

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Abstract

On-site underground background measurements were performed for the planned reactor-neutrino oscillation experiment KASKA at Kashiwazaki-Kariwa nuclear power station in Niigata, Japan. A small-diameter boring hole was excavated down to 70m underground level, and a detector unit for γ -ray and cosmic-muon measurements was placed at various depths to take data. The data were analyzed to obtain abundance of natural radioactive elements in the surrounding soil and rates of cosmic muons that penetrate the overburden. The results will be reflected in the design of the KASKA experiment.

Key words: reactor neutrino, neutrino oscillation, cosmic ray, radioactivity, low background

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1 Introduction

A new neutrino-oscillation experiment KASKA[1] is planned at Kashiwazaki-Kariwa nuclear power station in Niigata, Japan. It will make precise measurements of neutrino flux from the reactors in order to measure the yet undetected θ_{13} neutrino mixing angle. The detectors will be placed in deep underground vertical shaft holes. Two near detectors are planned inside the reactor site at a depth of 50 m in separate shafts, and two far detectors are planned outside the site, at a distance of about 1.6 km and a depth of 150 m in one shaft hole.

During October and November 2004, a boring study was conducted on the reactor site, at a place where one of the near detectors will be placed (NEAR-B position in Fig. 1). The purpose of the boring study was to obtain the soil samples needed for the planning of civil construction of the vertical shaft holes, and to measure backgrounds at the actual detector location in order to reflect in the detector design.

The boring hole extended down to 70 m underground, with a diameter of 66 mm. After the sample cores had been taken, a detector for measuring γ -ray and cosmic-muon background was deployed into the hole, and data were taken at various depths. The experimental setup of the measurement and data analyses are described in the following sections.

2 Experimental setup

The detector consisted of a NaI(Tl) scintillator for the γ -ray measurement and a pair of plastic-scintillators for the cosmic-muon measurement. The schematic of the detector is shown in Fig. 2.

The NaI scintillator had a diameter of 1 inch and a length of 2 inches, and was viewed by a Hamamatsu H8643 photomultiplier (PMT). The cosmic-muon

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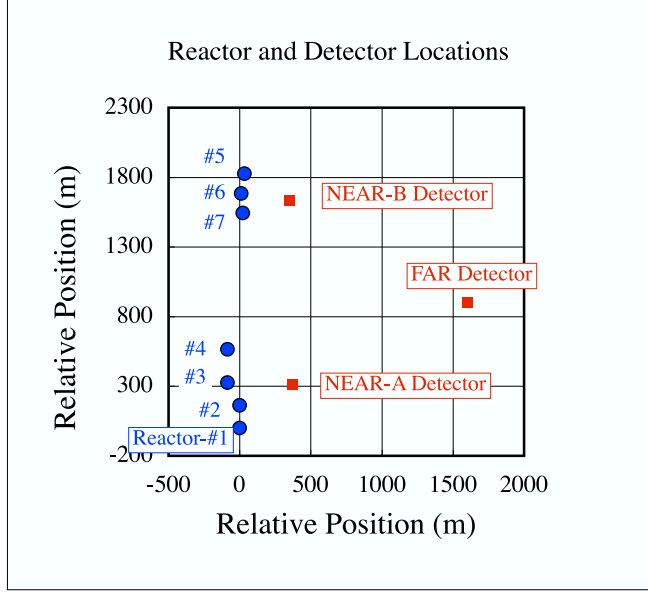


Fig. 1. The locations of reactors and detectors.

counter had two plastic scintillators of 1-inch diameter and 2 cm thickness, sandwiching a 1 cm-thick lead plate to reduce correlated Compton- γ background, and both scintillators were viewed by Hamamatsu H8643 PMTs.

The scintillators and PMTs were contained in a stainless-steel cylindrical vessel of 42 mm diameter and 670 mm length. Cables for high voltage(RG174/U) and signals(1.5D-QEV), 100 m long, were taken out of the vessel through small holes, and the vessel was made hermetic with 3M DP460 epoxy adhesive. Also a humidity sensor was put in the vessel to detect a possible water leak. The hermiticity of the vessel was tested up to 10 bars of water pressure.

After the core samples were taken, PVC pipes (inner/outer diameters 51/60 mm) were put into the hole to protect the hole surface. Then the detector was deployed into the hole using a stainless wire, and data were taken at various depths, down to 65 m from the surface. The level of the surface was found to be 30 m above the sea level, and the water level in the hole was found to be approximately at the sea level.

The data were taken with either of the three PMTs triggering above a threshold. Pulse heights of PMTs were recorded with a VME ADC (LeCroy 1182). In addition, discriminator output of each PMT was recorded with a bit register. Single rates of cosmic-muon PMTs were about 1 Hz, and their coincidence rate was between 4-17 events/hour, depending on the depth. The single rate of γ -ray PMT was between 15-35 Hz, depending on the depth.

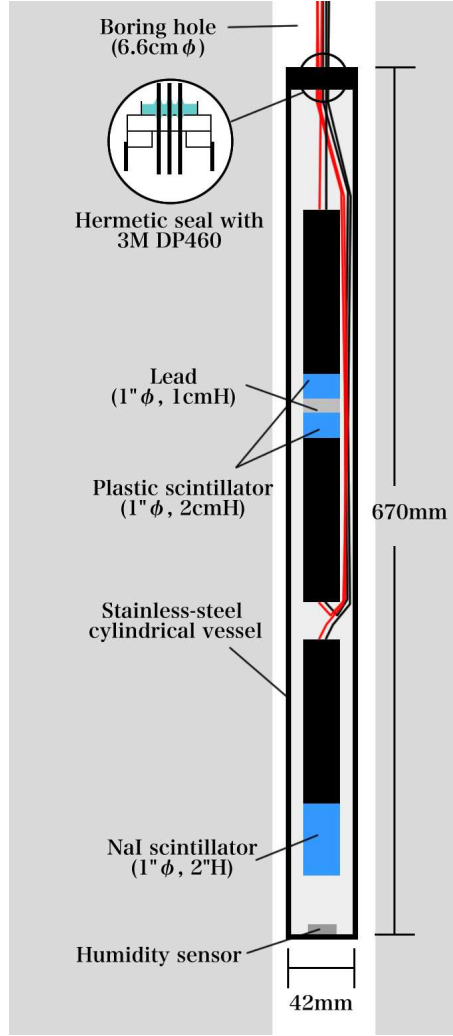


Fig. 2. The schematic of the detector.

3 γ -ray analysis

Figure 3 shows the measured γ -ray energy spectra at 15, 30, 50 and 65 m depths.

Distinct peaks at 1460 and 2600 keV are seen, with other small peaks. They correspond to 1461 keV γ 's from ^{40}K and 2615 keV γ 's from ^{208}Tl in the ^{232}Th chain. The analysis is made under the hypothesis that the sources are ^{238}U , ^{232}Th , and ^{40}K contained in the soil, and that the decay chains of ^{238}U and ^{232}Th series are in radio-equilibrium. To reproduce the spectra, Geant4 [2] simulations are performed, with a geometry consisting of (from outer to inner) soil space (100 cm diameter and 100 cm height, 30% water concentration), PVC pipe, water, stainless-steel vessel and NaI scintillator. For each of ^{238}U , ^{232}Th series, 30 γ -ray energies having largest branching ratios are considered [3], and for ^{40}K , single γ -ray of 1461 keV is considered in the simulation.

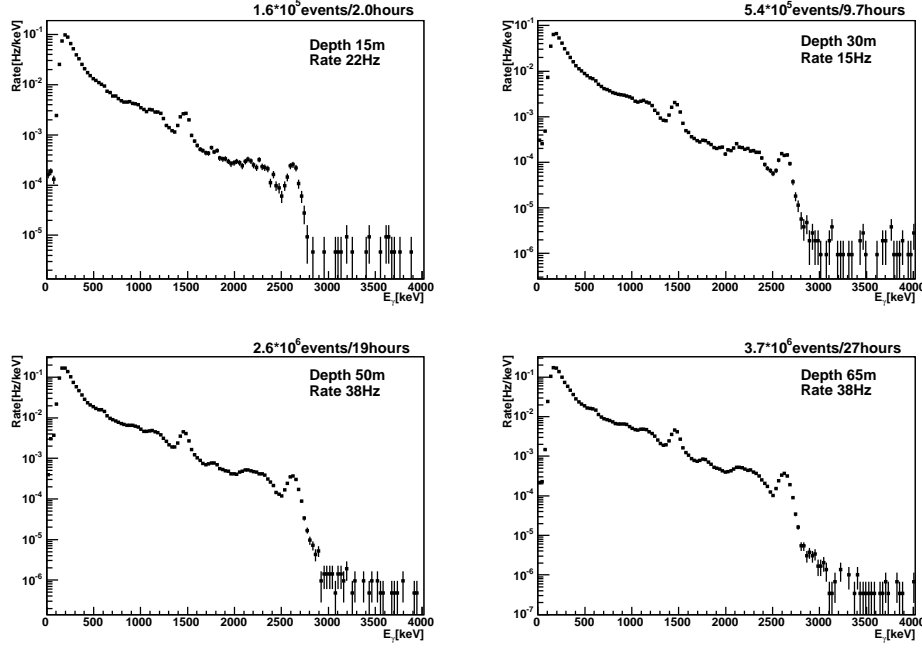


Fig. 3. The measured γ -ray energy spectra at 15, 30, 50 and 65 m depths.

The energies are smeared with a detector resolution of $\sigma(E)/E = 3.6\%/\sqrt{E(\text{MeV})}$, which reproduces the peak at 2615 keV. Figure 4 shows the simulated spectra from each source for 1 ppm weight concentration in the soil.

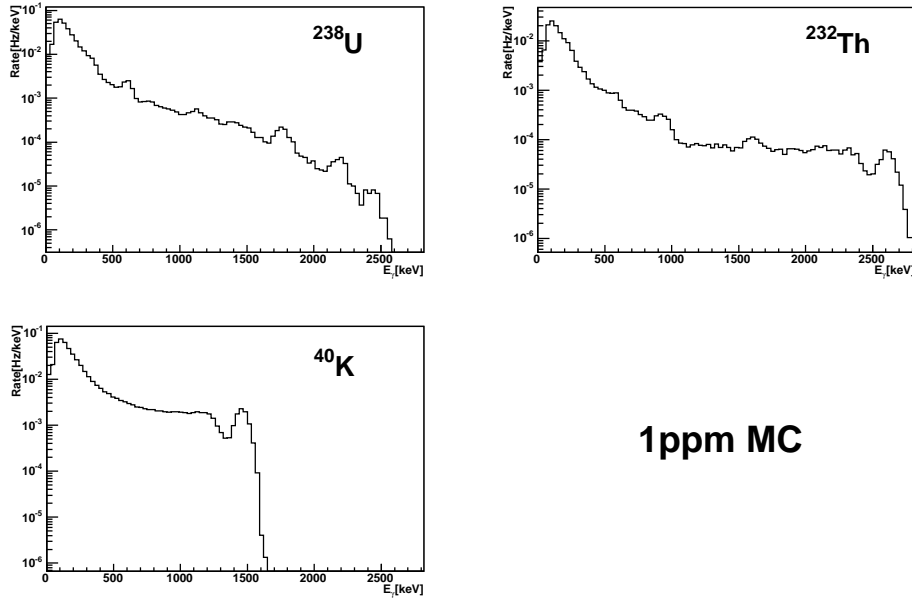


Fig. 4. The simulated spectra from each source for 1ppm weight concentration in the soil.

Then, a linear combination of the three sources are fitted to the measured spectra, and a χ^2 fitting for the region above 1200 keV is performed to obtain

the weight concentrations of the three sources. Table 1 shows the fitting results, and Fig. 5 shows the comparison of the data and the fitted spectrum from the simulation for the depth of 65 m. A good agreement is observed.

The notable difference in γ -ray rates for depths up to 30 m and for depths of 50m and above is coming presumably from different stratum structure at the location. The weight concentrations at 50 m are not very different from the estimation, so that it ensures the appropriateness of the current γ -ray shield design.

Table 1

Each series weight concentrations (ppm) obtained from the fitting

Depth	^{238}U	^{232}Th	^{40}K
15m	1.3 ± 0.06	2.7 ± 0.07	1.3 ± 0.03
30m	0.8 ± 0.02	2.0 ± 0.03	1.0 ± 0.01
50m	2.1 ± 0.03	6.3 ± 0.04	1.5 ± 0.01
65m	2.3 ± 0.02	6.1 ± 0.03	1.5 ± 0.007

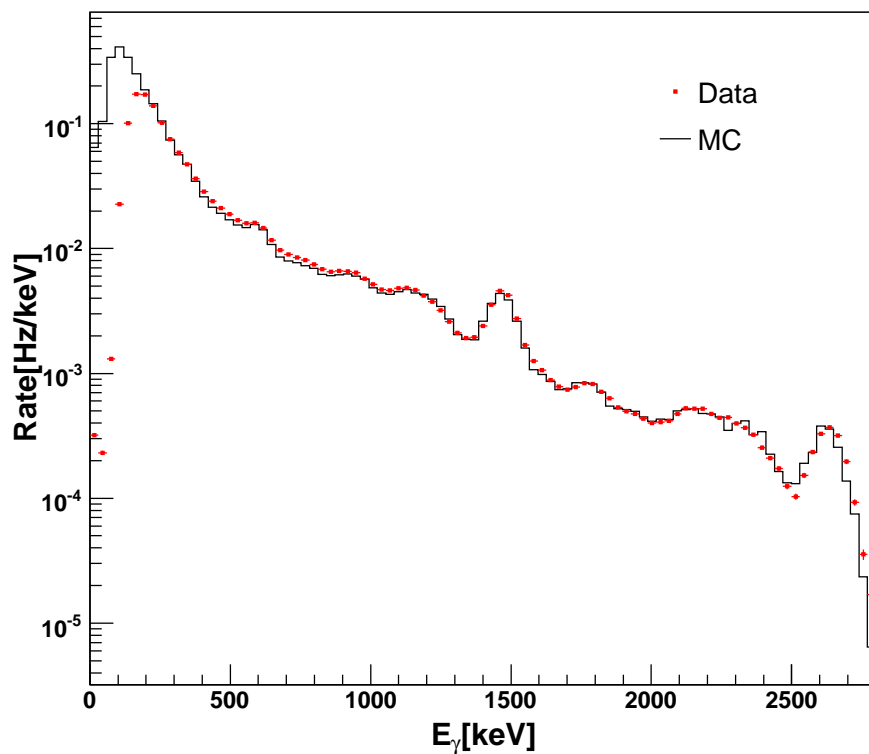


Fig. 5. The comparison of the data and fitted spectrum from the simulation for the depth of 65 m.

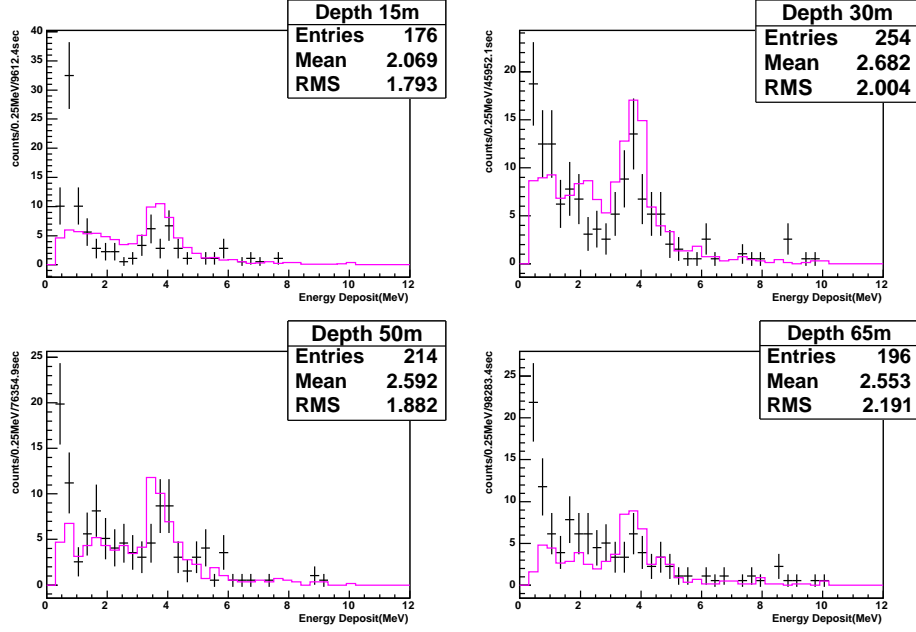


Fig. 6. Energy deposit in plastic scintillators of coincident hits ($E_{th}=0.4\text{MeV}$). The crosses show the measured data, while the histograms show the Geant4 simulation.

4 Cosmic-muon analysis

Figure 6 shows the energy deposit in the plastic scintillators measured at 15, 30, 50 and 65 m depths, when the coincidence of the two scintillators are taken. A peak corresponding to minimum ionizing particles (MIP) is clearly seen around 4 MeV, and also spectra of the environmental γ -rays are seen at low-energy region. The low-energy region also contains events in which the cosmic ray traversed only a part of the scintillator. Though the coincidence are taken, spectra of the Compton scattered γ -rays remain. A Geant4 simulation is compared with the measured data. The simulation generates muon flux at the surface, with a flat zenith-angle dependence. The energy spectrum of the muon is parameterized as in the following equation with the measured spectrum data of BESS [4] and CAPRICE [5] experiments.

$$\frac{dj_{\theta=0}(E)}{dE} = 0.0049 \{1.057 + 0.217E\}^{-3.26} \quad (/cm^2/sr/sec/(GeV/c)) \quad (1)$$

Then, the muons are tracked down in the soil space beneath the surface, and energy deposits in the scintillators are calculated. In Fig. 6, it is seen that the simulation fairly well reproduces the energy spectrum above 3 MeV, where the effect of environmental γ -rays is negligible. From the comparison of the measured and simulated rates above 3 MeV, the muon flux at each depth is well demonstrated by the empirical formula, which is shown in Fig. 7. In the

figure, fitted functions using an empirical formula [6],

$$I_v = \frac{1740000}{h + 400} (h + 11)^{-1.53} \times \exp(-7.0 \times 10^{-4}h) (/m^2/sr/sec)$$

(where h is the depth in mwe) are also given. In the fitting, the data rates near the surface are excluded since they may contain additional rates from electromagnetic showers. The agreement between the prediction is within 20%, and it ensures the estimation of the cosmic-origin background rates in the main detector.

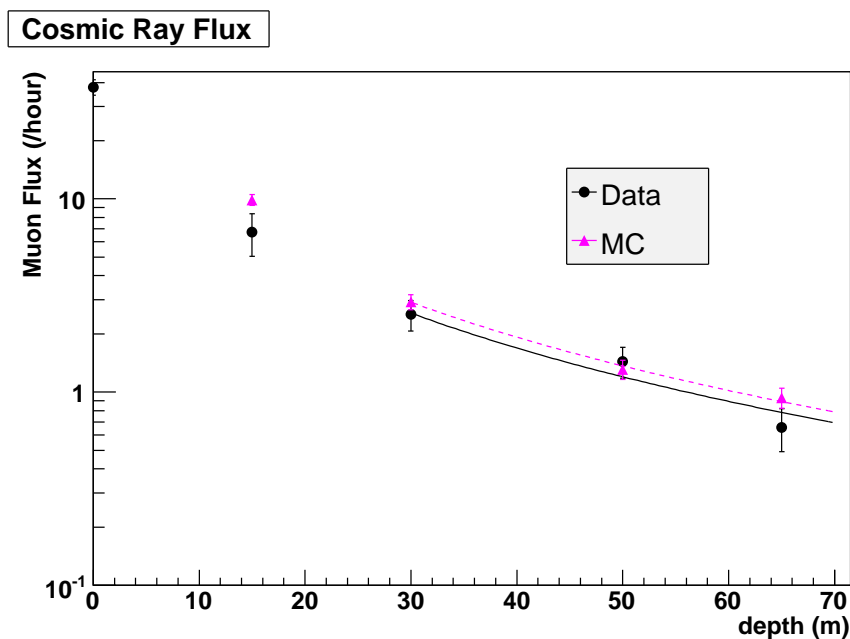


Fig. 7. Measured (circles) and simulated (triangles) rates above 3 MeV. Solid lines are fitted functions excluding the rates at the surface and 15m depth.

5 Summary

On-site underground background measurements were performed for the planned reactor-neutrino oscillation experiment KASKA at Kashiwazaki-Kariwa nuclear power station in Niigata, Japan. Gamma-rays and cosmic-muons were measured using a small detector deployed at various depths. Spectra of γ -rays were fitted and weight concentrations of radioactive elements at each depth of the surrounding soil were measured. Cosmic muon rates were obtained from the minimum-ionizing peaks of the data and compared with the simulation to evaluate its reliability. The results will be reflected in the design of the KASKA detector.

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References

- [1] Letter of Intent for KASKA, hep-ex/0607013.
- [2] <http://geant4.web.cern.ch/geant4/>
- [3] <http://www.radiochemistry.org/periodictable/index.shtml>
- [4] M. Motoki et al., Astropart. Phys. 19 (2003) 113.
- [5] J. Kremer et al., Phys. Rev. Lett. 83 (1999) 4241.
- [6] Chronological Scientific Tables, National Astronomical Observatory, Japan (2002).